

**FLAME RESISTANT FABRICS HAVING INCREASED STRENGTH****CROSS-REFERENCE TO RELATED APPLICATIONS**

5        This application is a continuation in part of U.S. Patent Application Serial No. 10/269,213, entitled "Flame Resistant Fabrics Having Increased Strength and Abrasion Resistance," which is a continuation in part of U.S. Patent Application Serial No. 10/165,795, entitled "Flame Resistant Fabrics Comprising Filament Yarns," both of which are entirely incorporated herein by reference.

**BACKGROUND**

10        Several occupations require the individual to be exposed to extreme heat and/or flames. To avoid being injured while working in such conditions, these individuals typically wear protective garments constructed of special flame resistant materials designed to protect them from both heat and flame.

15        To cite an example, firefighters typically wear protective garments commonly referred to in the industry as turnout gear. Such turnout gear normally comprises various garments including, for instance, coveralls, trousers, and jackets. These garments usually include several layers of material including, for example, an outer shell that protects the wearer from flames, a moisture barrier that prevents the ingress of water into the garment, and a thermal barrier that insulates the wearer from extreme heat.

20        Turnout gear outer shells typically comprise woven fabrics formed of one or more types of flame resistant fibers. In that the outer shell must withstand flame,

excessive heat, and abrasion, it must be constructed of a flame resistant material that is both strong and durable. The National Fire Protection Association (NFPA) provides guidelines as to the strength a fabric must have in order to be used in the construction of outer shells. According to NFPA 1971, 2000 edition, the fabric must exhibit a tensile strength of at least 140 pounds (lbs.) in the warp and filling directions, and a trapezoidal tear strength of at least 22 lbs. in the warp and filling directions. The NFPA provides detailed guidelines as to the manner in which testing is to be conducted to determine both tensile strength and tear strength.

## SUMMARY

Disclosed are flame resistant fabrics. In one embodiment, a flame resistant fabric includes a plurality of flame resistant body yarns that form a body of the fabric, and a plurality of relatively tough yarns provided in discrete positions within the fabric body, the relatively tough yarns comprising a filament yarn that includes a filament composed of one of polyolefin, flame resistant polyester, polytetrafluoroethylene, polyetheretherketone, polyetherimide, polysulfar, polyimide, polyamide, polyimideamide, polybenzoxazole, polybenzimidazole, carbon, and glass.

An embodiment of a method for forming a flame resistant fabric includes arranging a plurality of flame resistant spun yarns to form a body of the fabric, and forming a grid of relatively tough yarns in the fabric body, each relatively tough yarn comprising a filament yarn including a filament composed of one of polyolefin, flame resistant polyester, polytetrafluoroethylene, polyetheretherketone, polyetherimide, polysulfar, polyimide, polyamide, polyimideamide, polybenzoxazole, polybenzimidazole, carbon, and glass.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The disclosed fabrics can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale.

FIG. 1 is a rear view of an example protective garment.

5        FIG. 2 is a schematic representation of a first example fabric that can be used in the construction of the garment of FIG. 1.

FIG. 3 is a schematic representation of a second example fabric that can be used in the construction of the garment of FIG. 1.

10       FIG. 4 is a schematic representation of a first relatively tough yarn that can be used to form the fabric of FIG. 3.

FIG. 5 is a schematic representation of a second relatively tough yarn that can be used to form the fabric of FIG. 3.

FIG. 6 is a schematic representation of a third relatively tough yarn that can be used to form the fabric of FIG. 3.

15       FIG. 7 is a schematic representation of a fourth relatively tough yarn that can be used to form the fabric of FIG. 3.

FIG. 8 is a schematic representation of an alternative relatively tough yarn that can be used to form the fabric of FIGs. 2 or 3.

20       FIG. 9 is a schematic representation of a further alternative relatively tough yarn that can be used to form the fabric of FIGs. 2 or 3.

FIG. 10 is a schematic representation of a third example fabric that can be used in the construction of the garment of FIG. 1.

**DETAILED DESCRIPTION**

FIG. 1 illustrates an example protective garment 100. More particularly, FIG. 1 illustrates a firefighter turnout coat that can be donned by firefighter personnel when exposed to flames and extreme heat. It is noted that, although a firefighter turnout coat is shown in the figure and described herein, the present disclosure pertains to protective garments generally. Accordingly, the identification of firefighter turnout gear is not intended to limit the scope of the disclosure. For example, other protective garments include urban search and rescue garments and wildlands firefighting garments.

As indicated in FIG. 1, the example garment 100 generally comprises an outer shell 102 that forms the exterior surface of the garment, a moisture barrier 104 that forms an intermediate layer of the garment, and a thermal liner 106 that forms the interior surface (i.e., the surface that contacts the wearer) of the garment. In that it forms the exterior surface of the garment 100, the outer shell 102 preferably is constructed so as to be flame resistant to protect the wearer against being burned. In addition, the outer shell 102 preferably is strong and durable so as to be resistant to tearing and abrasion during use in extreme environments.

The fabric includes relatively tough yarns in the fabric body, for instance in a grid pattern. As is known in the art, “toughness” is a property that pertains to a material’s (in this case yarn’s) ability to resist breakage. The term “relatively tough” is used herein to describe yarns that have higher toughness than the remainder of the yarns (i.e., body yarns) of the fabric.

FIG. 2 is a schematic view of a first example fabric 200 that can be used in the construction of the protective garment 100, and more particularly the outer shell 102, shown in FIG. 1. As noted above, however, the fabric 200 could be used in the

construction of other protective garments either by itself or in combination with other fabrics. As indicated in the figure, the fabric 200 can be formed as a plain weave fabric that comprises a plurality of body yarns 206, including picks 202 and ends 204. Although a plain weave is illustrated and described herein, it will be appreciated that  
5 other configurations could be used including, for instance, a rip-stop, twill weave, or knitted configuration.

The majority of the body yarns 206 comprise spun yarns that are constructed of a flame resistant material such as meta-aramid, para-aramid, flame resistant cellulosic materials (e.g., flame resistant cotton, rayon, or acetate), flame resistant  
10 wool, flame resistant polyester, polyvinyl alcohol, polytetrafluoroethylene, polyvinyl chloride (PVC), polyetheretherketone, polyetherimide, polysulfar, polychlal, polyimide, polyamide, polyimideamide, polyolefin, polybenzoxazole (PBO), polybenzimidazole (PBI), carbon, modacrylic, melamine, or other suitable flame resistant material. Most preferably, the spun yarns are composed of at least one of  
15 meta-aramid, para-aramid, PBI, and PBO. Each body yarn 206 can comprise a single yarn or two or more individual yarns that are twisted, or otherwise combined, together. Typically, the body yarns 206 comprise one or more yarns that each have a yarn count in the range of approximately 5 to 60 cc, with 8 to 40 cc being preferred. By way of example, the body yarns 206 comprise two yarns that are twisted together,  
20 each having a yarn count in the range of approximately 10 to 25 cc.

In addition to the body yarns 206, provided in both the warp and filling directions of the fabric 200 are relatively tough yarns 208, whose construction is described in greater detail below.

The arrangement of the relatively tough yarns 208 within the fabric 200 can be  
25 varied depending upon the desired physical properties. In the arrangement shown in

FIG. 2, the fabric 200 is constructed such that the relatively tough yarns 208 are arranged in a grid pattern in which several body yarns 206 are placed between each consecutive relatively tough yarn 208 in both the warp and filling directions of the fabric. As an example, one relatively tough yarn 208 is provided in the fabric in both the warp and filling directions of the fabric for every approximately seven to nine body yarns 206. Alternatively, two or more relevantly tough yarns 208 can be woven along with each other in the fabric 200 to form a rip-stop fabric (see FIG. 10). Typically, the grid pattern is arranged so as to comprise a plurality of squares. To accomplish this, a greater number of body yarns 206 may need to be provided between consecutive relatively tough yarns 208 in the filling direction as compared to the warp direction.

Each relatively tough yarn 208 comprises a filament yarn that includes one or more individual continuous filaments. Accordingly, a given filament yarn can comprise a monofilament yarn or a multifilament yarn. In the latter case, several hundred continuous filaments that are twisted together may be used to form the relatively tough yarn 208. Each filament yarn comprises one or more individual filaments composed of a strong material such as polyolefin (e.g., high density polyethylene), flame resistant polyester, polytetrafluoroethylene, polyetheretherketone, polyetherimide, polysulfar, polyimide, polyamide, polyimideamide, polybenzoxazole (PBO), polybenzimidazole (PBI), carbon, glass, or combinations thereof. Of these, PBO, carbon, glass, and high density polyethylene (e.g., Spectra<sup>TM</sup> or Dynemma<sup>TM</sup>) are preferred. The weight of the filament yarns typically range from approximately 50 to 1000 denier, with the range of 100 to 600 denier being preferred.

Optionally, the fabric 200 can be configured so that the relatively tough yarns 208 do not protrude beyond the outer surface of the fabric such that the fabric shields the relatively tough yarns from abrasion. This end result can be achieved in a variety of different ways. In one solution, the relatively tough yarns 208 are constructed so as to have effective diameters that are equal to or less than those of the body yarns 206 that form the body of the fabric 200. In another solution, the linear density and/or weight of the relatively tough yarns 208 is less than or equal to that of the body yarns 206, assuming each has the same specific gravity.

FIG. 3 is a schematic view of a second example fabric 300 that can be used in the construction of the protective garment 100, and more particularly the outer shell 102, shown in FIG. 1. Again, the fabric 300 could be used in the construction of other protective garments either by itself or in combination with other fabrics. The fabric 300 is formed as a plain weave fabric that, like the fabric 200 of FIG. 2, comprises a plurality of body yarns 306, including picks 302 and ends 304.

The body yarns 306 have configurations similar to the body yarns 206 of the fabric 200. Therefore, a majority of the body yarns 306 of the fabric 300 comprise spun yarns that are constructed of a flame resistant material such as meta-aramid, para-aramid, flame resistant cellulosic materials (e.g., flame resistant cotton, rayon, or acetate), flame resistant wool, flame resistant polyester, polyvinyl alcohol, polytetrafluoroethylene, polyvinyl chloride (PVC), polyetheretherketone, polyetherimide, polysulfar, polychlal, polyimide, polyamide, polyimideamide, polyolefin, polybenzoxazole (PBO), polybenzimidazole (PBI), carbon, modacrylic, melamine, or other suitable flame resistant material. Each body yarn 306 can comprise a single yarn or two or more individual yarns that are twisted, or otherwise combined, together. Typically, the body yarns 306 comprise one or more yarns that

each have a yarn count in the range of approximately 5 to 60 cc, with 8 to 40 cc being preferred. By way of example, the body yarns 306 comprise two yarns that are twisted together, each having a yarn count in the range of approximately 10 to 25 cc.

In addition to the body yarns 306, provided in both the warp and filling  
5 directions of the fabric 300 are relatively tough yarns 308. The relatively tough yarns 308 each comprise at least one filament yarn having a configuration similar to the filament yarns described in relation to the fabric 200 of FIG. 2. Therefore, each relatively tough yarn 308 comprises a filament yarn that includes one or more  
10 filaments composed of a strong material such as polyolefin (e.g., high density polyethylene), flame resistant polyester, polytetrafluoroethylene, polyetheretherketone, polyetherimide, polysulfar, polyimide, polyamide, polyimideamide, polybenzoxazole (PBO), polybenzimidazole (PBI), carbon, glass, or combinations thereof. Of these, PBO, carbon, glass, and high density polyethylene (e.g., Spectra<sup>TM</sup> or Dynemma<sup>TM</sup>) are preferred. The weight of the filament yarns  
15 typically range from approximately 50 to 1000 denier, with the range of 100 to 600 denier being preferred.

As shown in FIG. 3, the relatively tough yarns 308 comprise two individual yarns 310 and 312 that are combined together and then woven (or otherwise provided) into the fabric 300. Both of the yarns 310 and 312 may comprise filament yarns  
20 composed of the materials discussed above. Alternatively, however, one of the yarns 310, 312 can comprise a spun yarn. Like the body yarns 306, the spun yarns of the relatively tough yarns can be composed of a material such as meta-aramid, para-aramid, flame resistant cellulosic materials (e.g., flame resistant cotton, rayon, or acetate), flame resistant wool, flame resistant polyester, polyvinyl alcohol,  
25 polytetrafluoroethylene, polyvinyl chloride (PVC), polyetheretherketone,



polyetherimide, polysulfar, polychlal, polyimide, polyamide, polyimideamide, polyolefin, (i.e., high density polyethylene) polybenzoxazole (PBO), polybenzimidazole (PBI), carbon, modacrylic, melamine, or other suitable flame resistant material. Normally, each spun yarn of each relatively tough yarn 308 has a  
5 yarn count in the range of 5 to 60 cc, with the range 8 to 55 cc being preferred.

The arrangement of the relatively tough yarns 308 within the fabric 300 can be varied depending upon the desired physical properties. In the arrangement shown in FIG. 3, the fabric 300 is constructed such that the relatively tough yarns 308 are arranged in a grid pattern in which several body yarns 306 are placed between each  
10 consecutive relatively tough yarn 308 in both the warp and filling directions of the fabric. As an example, one relatively tough yarn 308 is provided in the fabric in both the warp and filling directions of the fabric for every approximately seven to nine body yarns 306. Alternatively, two or more relevantly tough yarns 308 can be woven along with each other in the fabric 300 to form a rip-stop fabric (see FIG. 10).  
15 Typically, the grid pattern is arranged so as to comprise a plurality of squares. To accomplish this, a greater number of body yarns 306 may need to be provided between consecutive relatively tough yarns 308 in the filling direction as compared to the warp direction.

As with the fabric 200 of FIG. 2, the fabric 300 can be configured so that the  
20 relatively tough yarns 308 do not protrude beyond the outer surface of the fabric such that the fabric shields the relatively tough yarns from abrasion. This end result can be achieved by, for example, constructing the relatively tough yarns 308 so as to have effective diameters that are equal to or less than those of the body yarns 306 that form the body of the fabric 300, or constructing the relatively tough yarns 308 such that the

linear density and/or weight of the relatively tough yarns is less than or equal to that of the body yarns.

FIGS. 4-7 illustrate various examples of relatively tough yarns that can be used in the fabric 300 shown in FIG. 3. In these figures, it is assumed that a filament  
5 yarn and a spun yarn are combined to form the relatively tough yarn. As noted above, however, the relatively tough yarns can, alternatively, comprise two filament yarns that are combined together.

Beginning with FIG. 4, shown is a relatively tough yarn 400 that comprises first and second yarns 402 and 404, which are plied together. The first yarn 402  
10 comprises a filament yarn and the second yarn 404 comprises a spun yarn that are loosely twisted together so as to form an integral yarn that can be used as a pick or end as the case may be.

FIG. 5 illustrates a variant of the relatively tough yarn 400 shown in FIG. 4. In particular, the relatively tough yarn 500, like yarn 400, includes first and second  
15 yarns 502 and 504 that comprise a filament yarn and a spun yarn, respectively. However, the relatively tough yarn 500 is formed as a tightly-twisted yarn such that the first yarn 502 and second yarn 504 are more intimately associated along the length of the relatively tough yarn.

FIG. 6 illustrates a relatively tough yarn 600 in which a first (filament) yarn  
20 602 is loosely wrapped with a second (spun) yarn 604 to create a core-wrapped arrangement. Figure 7 illustrates a more tightly core-wrapped arrangement of a relatively tough yarn 700 that includes a filament core yarn 702 that is substantially completely surrounded by a pair of spun yarns 704. Although two yarns 704 are shown wrapped around the core yarn 702 in FIG. 7, it will be appreciated that fewer  
25 or greater such yarns could be wrapped around the core yarn in this manner.

Although the relatively tough yarn 308 has been shown and described as comprising two individual yarns that are combined together, three or more individual yarns could be combined, if desired, to form the relatively tough yarn (see, e.g., the discussion of yarn 700 above).

5           FIG. 8 illustrates an alternative yarn 800 that may be used to form a relatively tough yarn either alone (e.g., fabric 200, FIG. 2) or together with another yarn (e.g., fabric 300, FIG. 3), and incorporated into a flame resistant fabric to strengthen the fabric. The yarn 800 includes a filament core yarn 802 about which a plurality of individual staple fibers 804 are spun to form a fiber sheath 806 that surrounds the core  
10   yarn. By way of example, the staple fibers can be spun around the core yarn 802 using a dref spin procedure or air jet spinning process. The filament core yarn 802 and the staple fibers 804 can be constructed of one or more of the various materials identified above for respective construction of the filament and spun yarns identified above.

15           FIG. 9 illustrates a further alternative yarn 900 that may be used to form a relatively tough yarn either alone (e.g., fabric 200, FIG. 2) or together with another yarn (e.g., fabric 300, FIG. 3), and incorporated into a flame resistant fabric to strengthen the fabric. The yarn 900 comprises a stretch broken yarn that includes broken filaments 902 that may be twisted together. The broken filaments 902 can be  
20   constructed of one or more of the various materials identified above for construction of filament yarns. Although the yarn 900 may not be as strong as yarns comprising continuous filament, it will normally be stronger than the body yarns of the fabric in which the yarn 900 is used.

FIG. 10 is a schematic view of an example rip-stop fabric 1000 that can be  
25   used in the construction of the protective garment 100. The fabric 1000 comprises

body yarns 1002 that form the body of the fabric and that have composition and construction similar to any of those described above. In the fabric 1000, however, two relatively tough yarns 1004 are woven along with each other in a grid pattern within the body of the fabric to form a traditional rip-stop weave. In the example of  
5 FIG. 10, the relatively tough yarns 1004 comprise two individual yarns 1006 and 1008 that are combined together. Notably, groups of more than two relatively tough yarns 1004 may be used, if desired, to form the grid pattern. The resultant fabric 1000 typically has a weight of approximately 3 to 12 ounces per square yard (osy).

With the arrangements disclosed herein, the tear strength of the fabric is  
10 increased due to the provision of the relatively tough yarns. Although the relatively tough yarns have been described as comprising filaments, it is noted that the relatively tough yarns could, alternatively, comprise non-filament yarns, such as spun yarns, depending upon the material used to construct the yarns. For example, that relatively tough yarns can comprise one or more PBI spun yarns that comprise PBI fibers either  
15 exclusively or in a blend with other fibers.